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The energy metabolism of China and India between 1971 and 2010: Studying the bifurcation

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ABSTRACT

This paper presents a comparison of the changes in the energetic metabolic pattern of China and India, the two most populated countries in the world, with two economies undergoing an important economic transition. The comparison of the changes in the energetic metabolic pattern has the scope to characterize and explain a bifurcation in their evolutionary path in the recent years, using the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach. The analysis shows an impressive transformation of China's energy metabolism determined by the joining of the WTO in 2001. Since then, China became the largest factory of the world with a generalized capitalization of all sectors, especially the industrial sector, boosting economic labor productivity as well as total energy consumption. India, on the contrary, lags behind when considering these factors. Looking at changes in the household sector (energy metabolism associated with final consumption) in the case of China, the energetic metabolic rate (EMR) soared in the last decade, also thanks to a reduced growth of population, whereas in India it remained stagnant for the last 40 years. This analysis indicates a big challenge for India for the next decade. In the light of the data analyzed both countries will continue to require strong injections of technical capital requiring a continuous increase in their total energy consumption. When considering the size of these economies it is easy to guess that this may induce a dramatic increase in the price of energy, an event that at the moment will penalize much more the chance of a quick economic development of India.

Contents

1. Introduction

“Peak oil” defined as the peak of conventional oil extraction is determining the beginning of the end of cheap fossil energy and therefore it should be considered as a turning point in recent

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economic history. Associations such as ASPO have been warning about the problem for a long time, and recently even the International Energy Agency (IEA) admitted in its *World Energy Outlook 2011* that the peak of 70 million barrels of daily crude oil production was reached in 2008 and has not been regained again [1]. The current optimism shown by IEA [2] with new shale oil and gas discoveries is contested in the academia and investment worlds for not being so financially attractive as claimed by speculators [3]. This, along with the tar sands troubles [4] leaves the importance of conventional oil untouched. The overwhelming dependence on cheap fossil fuels of the current economic model will certainly generate stress on the pattern of economic growth in coming decades when these fossil fuels will be no longer cheap. The transition to a global economy free of fossil fuels is certainly desirable to reduce socio-environmental impact – especially in extraction areas – but the complexity of the global economy is locked-in on existing technical and political institutions that make such a transition very difficult in the short run. The relentless growth of oil demand, coupled with the stagnation of conventional oil extraction, it is expected to trigger important increases in oil prices, which in turn may deepen the economic crisis in the U.S., Japan and Europe. Although the economic stagnation in these countries has slowed its energy consumption, global demand has continued to increase due to the strong growth in emerging countries like China, India, Brazil and Russia [5]. This is the reason why, the study of these fast transition countries and, in particular, of those with a very significant population size, is extremely important.

This paper presents a biophysical analysis of changes in the energy metabolic pattern of China and India for the period 1970–2010 by using the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) accounting method. These two countries are extremely interesting since they are the most populated countries in the world – together around 2.6 billion inhabitants in 2011, 37% of the world's population – and they are undergoing an important metabolic transition [6]. As result of this fact, China was the largest world energy consumer and India the fourth in 2011 (BP Statistical Review of World Energy [5]). This paper studies the biophysical roots of economic growth analyzing changes in the energetic metabolic pattern associated with the analogous changes in the characteristics of the structures of consumption and production within the economy. In this way it becomes possible to individuate and explain those relevant characteristics determining differences in the energetic metabolic pattern of China and India, possible future trends and potential environmental consequences. There are several studies about China and India energy economy – e.g. literature review of China's one in [7]. Nonetheless, the quantitative analysis found in available literature does not take into account the crucial difference between flows, funds and stocks [8]. For example, if we want to study changes in the relation between GDP (a monetary flow) and energy consumption (an energy flow), the standard approach is to look at changes in a flow–flow ratio (GDP/total energy throughput) as it happens with Economic Energy Intensity (EEI). This procedure can lead to serious troubles as shown by Fiorito [9]. This problem is solved by adopting the MuSIASEM method of accounting based on the integration of flow-fund ratios [10]. In this method the EEI is defined as a ratio over two flow-fund ratios – energy metabolic rate (total energy throughput/total human activity = energy metabolic rate – MJ/h of human activity, average over 1 year) divided by economic labor productivity (GDP/total human activity = ELP – US$/h of human activity, average over 1 year). By generating a ratio over two flow-fund ratios we can address the issue of scale, considering heterogeneity in the structural components of the economy when comparing different countries in term of energy use efficiency and labor productivity [11]. In this sense, studies of energy efficiency based on energy intensity (see Table 4 of [7]) carried put at the level of the whole country misses the existence of important differences at the level of specific economic compartments. On the contrary, a multi-scale analysis based on flow-fund ratios can identify the role of each economic sector in determining both the economic labor productivity and the energy consumption of the country, when considered as a whole. Therefore, this method makes it possible to identify and compare the characteristics of "apples" and "oranges" and generate more robust forecasts of possible future scenarios.

The rest of the paper is organized as follows: Section 2 briefly introduces the methodology; Section 3 presents the results and interprets them; and finally Section 4 lists the most important conclusions that have been reached. Appendix A presents the tables with the main data analyzed.

2. Methodology

The concept of societal metabolism refers to the set of transformation processes of energy and materials taking place in a given society which are necessary for reproducing the society over time. This study must be organized bridging two non-equivalent narratives: (i) in relation to internal constraints – focusing on the set of transformations under human control (the interaction of the parts inside the black-box); (ii) in relation to external constraints – focusing on the existence of favorable conditions determined by processes outside human control (the interaction of the black-box with its context). Societal metabolism studies had a boom in the 70s due to the oil crisis, which highlighted the need to better understand human dependence on natural resources, especially energy-related ones. As indicated by Ramos-Martin et al. [12], these studies focused on the analysis of the interaction of socio-economic systems with their environment. Many of them were widely used to study farming systems and human communities [8,13–26].

The research methodology used here is based on the approach of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). This analysis framework was introduced by Giampietro and Mayumi [11,27]; see also [10,28]. This approach is an application of Georgescu-Roegen's flow-fund scheme [8,29] and seeks to provide a socioeconomic and biophysical analysis from complex autopoietic system theory inspired by Maturana and Varela [30,31].

As pointed out by Giampietro et al. [10], when studying metabolic systems the distinction between fund and flow becomes fundamental to understand not only the way systems work, but also their sustainability over time. Flow categories are those elements that enter but do not exit the system representation or exit without having entered – e.g. fossil energy or a new product. Instead, fund categories are those agents that preserve their identity over the duration of the representations and transform input flows into output flows – e.g. capital, people, or Ricardian land. Funds are the elements to be sustained when speaking of sustainability: they have to be reproduced in the process. Another useful distinction is that of endosomatic and exosomatic metabolism. Endosomatic metabolism is one that refers to food energy and which is transformed inside the human body in order to maintain its activity and development. Exosomatic metabolism is one that refers to energy converted outside the human body, but still converted into applied power under human control, in order to facilitate the work associated with human activity, which gained special importance since the industrial revolution [24,32].

MuSIASEM is an accounting scheme which allows the linking of biophysical and socioeconomic variables in an integrated manner. This makes it possible to bridge two non-equivalent views of the

metabolic pattern of a given society: (i) the external view dealing with potential environmental constraints such as availability of resources, waste generation and absorption capacity (feasibility of the metabolic pattern according to the characteristics of processes outside human control); and (ii) the internal view dealing with potential technical and economic constraints such as the technical coefficients and the requirement of production factors (viability of the metabolic pattern according to the characteristics of processes under human control).

In relation to the analysis of environmental constraints the MuSIASEM approach can be used to generate an Environmental Impact Matrix. Examples of applications are given in [33]. This requires mapping the flows metabolized by a society – both on the supply and the sink side – in spatial terms (using GIS) in order to be able to study the impact that these flows have on the metabolic pattern of embedding ecosystems. When mapping flows against ecological funds in spatial terms it becomes possible to check whether the density of the metabolized flows (both on the supply or the sink side) is harmful for the stability of environmental processes.

Regarding the analysis of socio-economic constraints, biophysical variables are combined with monetary ones to characterize the different activities making up the economy. This provides a biophysical overview of the economic process in the form of a quantitative representation of the metabolic pattern of a society described in relation to the profile of allocation of human activity in the different compartments of society. This analysis shows the interrelationships between demographic, economic and environmental constraints. To do this, MuSIASEM integrates data referring to different levels of organization and scales (national, regional, local and household) and different dimensions of analysis.

Finally, it should be noticed that the MuSIASEM is an accounting method and not a model. For this reason the quantitative results depend on the choice of categories of accounting made when defining the characterization of the metabolic pattern. For example, in this study, we accounted the energy consumed by private cars in the category: “energy consumption of the household”, whereas this energy is accounted in official energy statistics in “transportation”. For this reason, MuSIASEM requires a pre-analytical agreement about the relevance of the choice of accounting categories. In this study we did not consider the effects of trade, whereas this effect is considered in other applications of MuSIASEM [33]. Finally, the accounting of MuSIASEM is static: it checks the congruence of the values of variables defined across different levels and scales within the chosen representation. However, it does not describe dynamics that can only be observed by adopting a scale at the time.

When studying the socio-economic side, biophysical variables can be combined with monetary ones to produce a ‘record’ of time use and exosomatic energy consumption in the different activities that make up the economy. This provides a biophysical overview of the economic process in the form of a quantitative representation of a metabolic pattern, showing the interrelationships between demographic, economic and environmental constraints.

In conclusion, MuSIASEM integrates data from different levels (national, regional, local and household) and different issues such as time use, land use and energy consumption of different activities and production sectors.

In this study the chosen analytical framework (called in the MuSIASEM jargon “the grammar” [10]) distinguishes between three levels of analysis (see Fig. 1): Level n, which reflects country-level variables; level $n-1$, which breaks down the values of level n between the Paid Work sector (PW, comprising all activities generating value added) and the household sector (HH); and level $n-2$, which breaks down the Paid Work sector among three lower level components – the agricultural sector (AG), the industrial and construction sector, including energy and mining (PS) and services and government (SG). The metabolic characteristics of the components defined at these different levels are defined using a combination of:

- Extensive variables: (i) Human Activity (FUND) – HA_i, measured in hours of human activity in the sector over the year; and (ii) Energy Throughput (FLOW) – ET_i, measured in GJ of exosomatic energy in the sector (expressed in Gross Energy Requirement thermal) over the year; and (iii) economic output (FLOW) – GDP_i, measured in the conventional way;
- Intensive variables: (i) Exosomatic Metabolic Rate (FLOW-FUND ratio) – EMR_i, measured in Gross Energy Requirement (thermal) per hour of human activity in the sector; and (ii) Economic Labor Productivity (FLOW-FUND ratio) – ELP_i the amount of sectorial GDP per year divided by the hours of human activity in the Paid Work in that sector;

Data for total energy consumption and by sector were obtained from the Energy Balances of the International Energy Agency dataset [34]. The energy consumption of transport has been distributed among domestic, industrial and services sectors using the following rule. The share of the household sector has been calculated on the basis of: (i) the number of private vehicles – motorcycles and cars [35,36]; (ii) annual distance traveled [37,38]; and (iii) average fuel consumption per year of motorcycles and cars [39,40]. For years in which these data are unavailable we have interpolated the values according to the available data on the basis

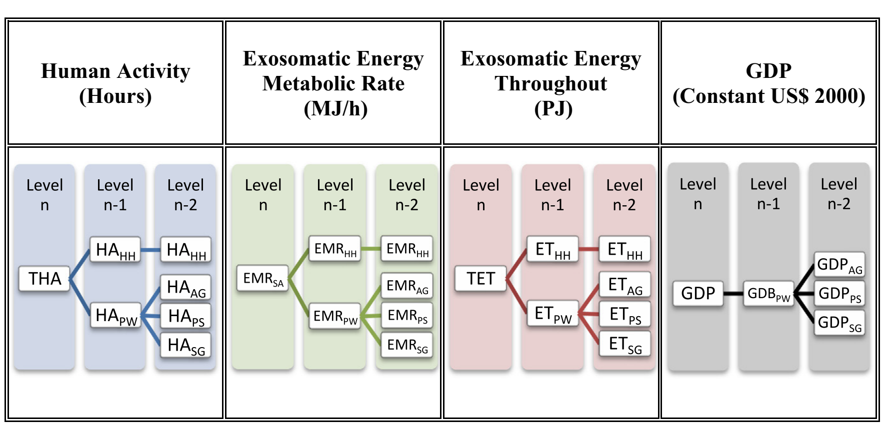

Fig. 1. Dendrograms of exosomatic energy metabolism, human activity and GDP.

of existing trends. For instance, that share was 25.8% in 1985 in the case of China, so we assumed a share of 25% for the previous years. In the case of India, we use a share of 25% for the years before the first observation (26,8% in year 2001) and 37% for the years after the last observation available (37% in 2006). The rest of energy consumption in transportation (total-household) was split between the services sector (80%) and the industry sector (20%) assuming that the majority of trucks used for transportation in these countries are owned by the drivers and therefore belong to the transportation sector (service) [10].

Data concerning hours of total human activity were obtained from the population statistics of each country – NBSC of China [35] and India from the OECD [41] – and multiplied by 8760 to calculate the total amount of human activity per year expressed in hours (using the convention of 365 days and 24 h per day). The hours of human activity in the Paid Work sector (HA_{PW}) have been obtained from statistics of employment and hours of work per week by economic activity from the ILO [42] and supplemented with World Bank [43] figures. For China, 47 h/week and 50 weeks/year have been assumed, making a total of 2350 working hours per year. For India, 46 h/week and 49 weeks/year have been assumed making a total of 2254 working hours per year.

Data concerning human activity in the Paid Work category by sector of economic activity – HA_{AG}, HA_{PS} and HA_{SG} – have been obtained from employment data by sector that is available for China in the NBSC [35] and for India in the Planning Commission [44]. Hours of human activity for the household sector (HH) have been obtained by the difference between PW and the total (Total Human Activity = Population × 8760): $HA_{HH} = THA - HA_{PW}$.

GDP statistics have been obtained from the World Bank [43] and GDP by sector – GDP_{AG}, GDP_{PS} and GDP_{SG} – constructed from the share of GDP by economic sectors from UN [45]. The intensive variables such as EMR_i, ELP_i have been obtained using the following equations:

$$EMR_i = \frac{ET_i}{HA_i} \tag{1}$$

$$ELP_i = \frac{GDP_i}{HA_i} \tag{2}$$

In this way it becomes possible to establish a relation between the changes in the Economic Energy Intensity of the whole country (EEI_{AS} – Average Society = TET/GDP) and the changes in the various compartments (EEI_i – Sector $i = EMR_i/ELP_i$) according to the following relation:

$$EEI_{AS} = \frac{TET}{GDP} = \frac{\sum \boldsymbol{x_i} \mathbf{EMR_i}}{(\sum \boldsymbol{x_i} \mathrm{ELP}_{\boldsymbol{i}}) \times \frac{HA_{PW}}{THA}} \quad \left[\text{where } \boldsymbol{x_i} = \frac{HA_{\boldsymbol{i}}}{THA}\right] \tag{3}$$

This relation makes it possible to study the factors determining changes in EEI across different hierarchical levels of analysis (at the level of economic sectors and subsectors). These factors refer to: (i) the biophysical characteristics of the various sectors (including the household sector) described by their EMR_i and their size, measured in the fraction of hours per year over the Total Human Activity; (ii) the economic characteristics of the various sectors (only in relation to the compartments defined in the Paid Work) described by their ELPi and their size, measured in the fraction of hours per year over the Human Activity in Paid Work; and (iii) the demographic structure (dependency ratio) and other socio-economic variables (work load per year, unemployment) determining the ratio HA_{PW}/THA (the relative size of the hours of human activity per year in the PW sector and THA per year).

3. Results and discussion

3.1. At the level of the country (level n)

This level of analysis presents the main indicators aggregated at the country level such as the extensive variables TET, THA and GDP, and the intensive ones EMR_{AS} or GDP per capita.

Tables A1 and A2 (see Appendix A) list the most relevant data for level n in China and India between 1971 and 2010. Figs. 2a and 3a show the evolution of the total energy consumption (TET) and the GDP in both countries between 1971 and 2010. In the case of China (Fig. 2a), the total energy consumption has increased more than six fold in the 39-year period studied, implying a compounded annual growth rate (CAGR) of nearly 5% for the same period. Note that since 2001 – when China joined the World Trade Organization (WTO) – the CAGR has been around 8%, which means that the energy consumption has doubled in just nine years, going from 50,300 PJ in the year 2001 to 101,200 PJ in 2010. To emphasize the importance of this change, one should note that China has increased its share of global primary energy consumption from 11.9% in 2001 to 18.9% in 2010. As regards to the GDP of China, it has shown a positive trend with a CAGR of 9%, particularly marked from China's entry into the WTO – as happened with energy – and which is around 11% for the latter period 2001–2010.

The correlation between TET and GDP is repeated in the case of India (Fig. 3a). However, India shows a more gradual evolution than China, and both variable values are considerably lower in absolute terms, a difference larger than what could be expected from the difference in population size between the two countries. Turning to the evolution of total energy consumption, India has increased more than 4 times in the 39-year period represented and shows a CAGR of 4%. Unlike China, India has not experimented an abrupt trend change in the first decade of the XXI century and

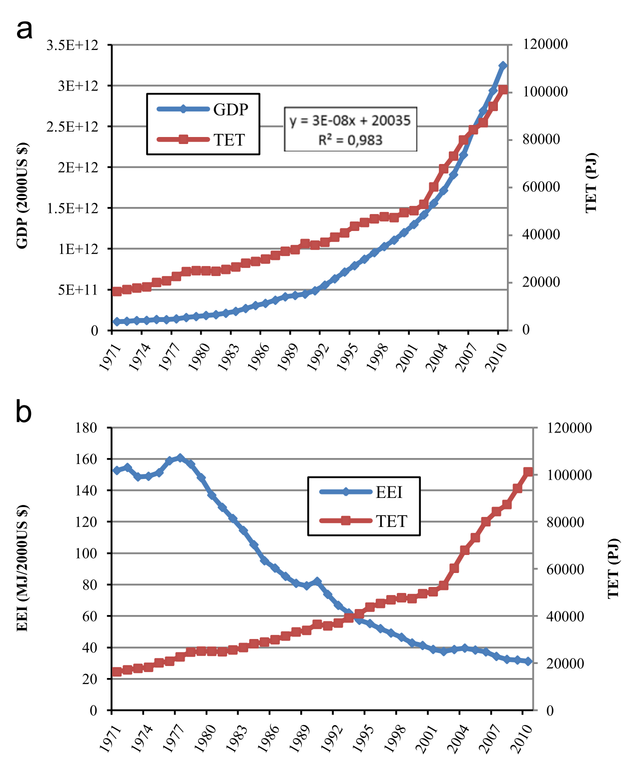

Fig. 2. (a) Evolution of total energy consumption (TET) and GDP of China between 1971 and 2010, as constructed from data provided in Table A1. (b) Evolution of TET and economic energy intensity (EEI) of China between 1971 and 2010, as constructed from data provided in Table A1.

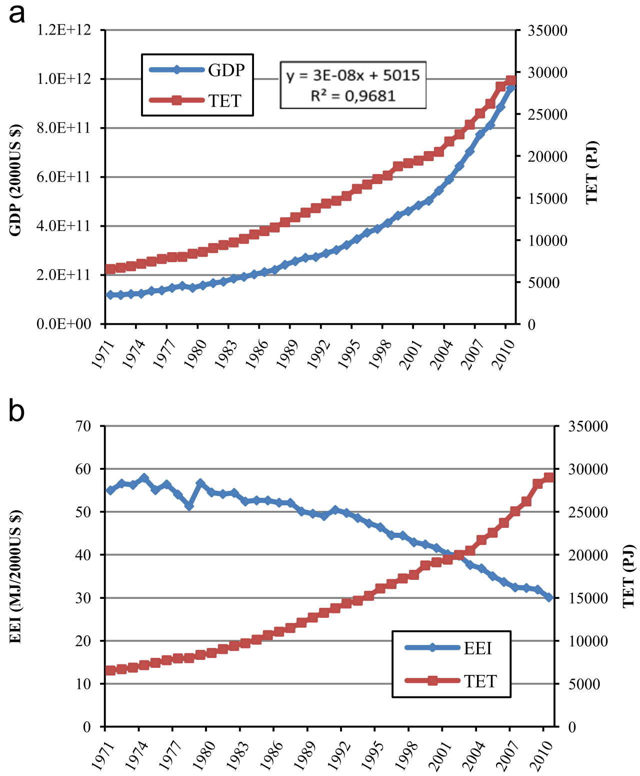

Fig. 3. (a) Evolution of total energy consumption (TET) and GDP of India between 1971 and 2010, as constructed from data provided in Table A2. (b) Evolution of TET and economic energy intensity (EEI) of India between 1971 and 2010, as constructed from data provided in Table A2.

the CAGR between 2001 and 2010 stood at 4.5%, only a half point higher than the average for the whole period studied (4%). In comparison this value is nearly half of that of China for the same period (8%). Yet, the increase in energy consumption for the latter period is not negligible, and although it did not double as in the case of China, it increased almost 40% from 19,448 PJ in the year 2001 to 29,001 PJ in the year 2010. This implied that India moved from consuming 4.6% of World energy in 2001 to consuming 5.4% of World energy in 2010.

It should be noted that both China's and India's increase in TET it is not only due to a growth in population (THA), but also to an increase in energy consumption per capita (EMR) – Tables A1 and A2. As will be seen in the next section, this increase in energy consumption is mainly due to the greater capitalization of the Paid Work sector (EMR*i* of the sector within PW) and some increase in domestic consumption (the EMR_{HH} of the household sector).

With respect to the GDP of India, we can see a growing trend with a CAGR of about 5.5% between 1971 and 2010, which greatly increases during the stretch between 2001 and 2010 reaching almost 8%. Despite the difference in growth rates between China (11%) and India (8%) we are dealing with a very high value when compared to the performance of other countries in the same period from 2001 to 2010: Brazil 3.9%, Russia 4.8%, Chile 3.9%, Venezuela 3.1%, Germany 0.9%, Spain 1.9%, Australia 3.2%, Canada 1.9% and the USA 1.6% [43].

Figs. 2b and 3b show the evolution of the total energy consumption (TET) and economic energy intensity (EEI_{AS}) for China and India between 1971 and 2010. As can be seen on these, values of EEI_{AS} — energy required to generate a unit of GDP – decreases significantly in the case of China and more tenuously in India. Tables A1 and A2 show how energy intensity for the period studied has been reduced approximately by a factor of 5 in China, while it has not even been halved in India. However, in spite of this reduction in the ratio TET/GDP, the total energy consumption has increased 6 times in China and over 4 times in India during the same period of time. This fact highlights the importance of avoiding to use an intensive variable determined by a ratio FLOW/FLOW (GDP/TET), as often done with EEI, to study the environmental effect of an increase in GDP. In fact, it is possible that the decrease in the ratio GDP/TET is offset by an increase in THA (population) and EMR (consumption per capita) associated with an increase in ELP (generation of added value per hour of human activity). As result of this fact, there is not any direct correlation between a reduction of GDP/TET and a reduction of environmental impact (for more on this see [10]). It should also be noted that if one wants to use proxy variables to assess environmental impacts one has to use extensive variables – i.e. measuring the actual amount of flows required or dumped into the environment – since the use of intensive variables (reflecting ratios of flows over flows or flows over funds) can lead to this kind of errors. Thus, the environmental impact of the economic process (both on the supply and sink side) should be based on TET because it is strongly correlated with the consumption of materials and the generation of environmental liabilities [46]. In this sense, Figs. 2b and 3b show that China and India have made impressive gains in their ability to use energy, but this has not reduced their dependency on fossil energy nor their environmental impact. Their GDPs are growing at an annual rate of around 10% – which implies doubling their size every 7–8 years – with their governments making plans to continue doing so. The strong correlation between GDP and TET suggests that the social and environmental impact will continue to increase in the coming years.

3.2. At the split between production and consumption (level n-1)

The performance of China and India at national level shown in the previous section can be better understood if the energy consumption, the generation of added value and the use of human activity within the economy are analyzed at a lower scale (level $n-1$), which distinguishes between activities where economic production takes place generating added value – in Paid Work sector (PW) – and activities where consumption takes place – in the household sector (HH). Households are responsible for the maintenance and reproduction of the fund "human activity" (HA), which means that the human activity, energy and materials are required to reproduce and enhance the FUND human activity, which is essential in the definition of a socio-economic system. In addition, when analyzing the metabolic pattern at this level of analysis it becomes possible to avoid the limitations of "per capita" indicators missing important information on the demographic structure of the society, which affects the performance of the economy. This analysis of the effect of the demographic structure is obtained by assessing the fraction of the FUND human activity in the Paid Work sector (HA_{PW}=hours per year in Paid Work) in relation to the total hours of human activity per year (THA= population $\times$ 8760). This fraction depends on demographic and socio-economic characteristics (the dependency, the employed population, the weekly hours of work and holidays). Tables A3 and A4 (see Appendix A) report the most relevant data from the level $n-1$ for China and India between 1971 and 2010.

From Tables A3 and A4, it can be seen that in 1971 the energy consumption in the production and households was relatively similar: ET_{PW}=8100 PJ and ET_{HH}=8200 PJ – about 50–50% in China; ET_{PW}=3000 PJ and ET_{HH}=3600 PJ – about 45–55% in India. However, in 2010 energy consumption in production became much higher than in households, due to the strong capitalization processes that occurred in both countries: ET_{PW}=83,000 PJ

and ET_{HH} = 18,200 PJ – about 83–17% in China; and ET_{PW} = 20,900 PJ and ET_{HH} = 8,100 PJ – about 72–28% in India.

When considering the share of human activity allocated to Paid Work (HA_{PW}) out of total (THA) we get a much lower value for India – 10% of THA – than for China – 15% of THA – between 1990 and 2010. It should be noted that fraction of HA_{PW}/THA for China is very high when compared to other countries like Spain with 7.2% in 2006 [47], Bulgaria and Hungary with 7–8%, Poland with 8–9% and 9–10% for Romania between 1995 and 2004 [48], Brazil with 9.3% and 11.3%, Chile with 7.8% and 9.9%, and Venezuela with 7.3% and 9.9% in 1980 and 2000 respectively [49], or Australia with 9–10%, Canada with 8–9.5% and the U.S. around 10% between 1990 and 2008 [50].

The main reason for the high value in China is the low dependency ratio that characterizes the demographic structure of China. This peculiarity is due to China's one-child policy, which has made the child dependency ratio very low in this country (24.4% in 2010), almost half as much as in India for the same year (46.6%) [51]. However, in the coming years it is expected that due to the ageing of China's population the dependency ratio will increase (on the elderly side) reducing the effect of the low child dependency ratio. According to Wolf et al. [51] it is expected that by 2030 China's dependency ratio will overtake that of India.

Following Cleveland et al. [52], Hall et al. [23], and Pastore et al. [53] Giampietro et al. [10] suggest that in the MuSIASEM approach the amount of energy consumed per hour of labor (EMR_{PW}) can be used as a proxy for the level of technical capitalization of the economy, and the amount of energy consumed per hour in households sector (EMR_{HH}) can be used as a proxy for the material standard of living. The first proxy is highly relevant in a context of cheap energy where the capitalization of the industry goes in the direction of investing in machinery to replace manual labor and thus increase the productivity of work. This results in greater mechanization and automation of production that will generate a direct increase in exosomatic energy consumption per hour of work (EMR_{PW}). In the second case, higher energy consumption in households (EMR_{HH}) is a clear indication that the households are enjoying more energy services (home appliances, mobility with private vehicles, heating and air conditioning, etc.), which make household chores easier, improve mobility and increase the overall comfort at home.

The pace of growth of EMR_{PW} of India and China in the period 1973–2010 is shown in Fig. 4. In a first period (1980–2001) India went from a value of EMR_{PW} of 7.46 MJ/h in 1980 to a value of 15.17 MJ/h in 2001, while China went from a value of EMR_{PW} of 14.72 MJ/h to a value of 21.91 MJ/h. These values reflect a similar growth pattern in the two countries. Things dramatically changed after the year 2001 (when China joined the WTO); in the second period (2001–2009) China had an annual growth rate of 8.8%

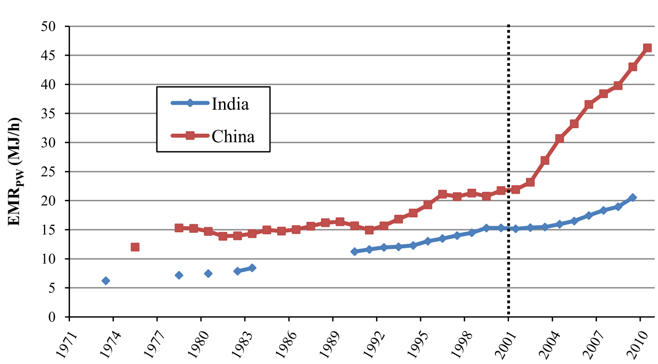

Fig. 4. Level of capitalization per worker in China and India between 1973 and 2010, as constructed from data provided in Table A3 and A4.

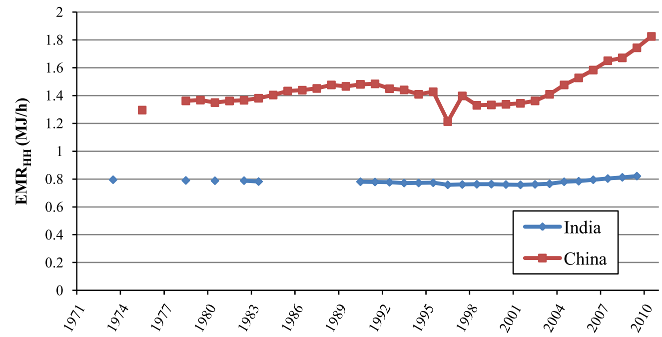

Fig. 5. Capitalization of the household sector in China and India between 1971 and 2010, as constructed from data provided in Table A3 and A4.

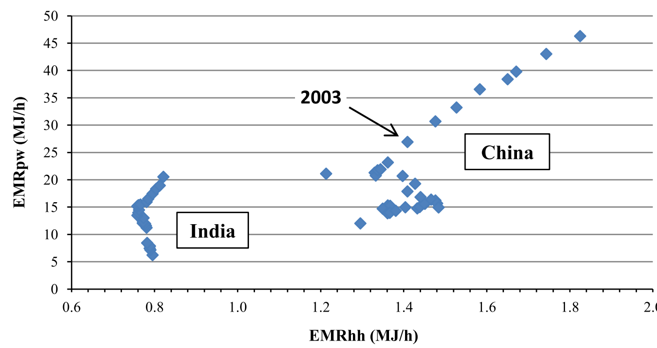

Fig. 6. EMR_{PW} versus EMR_{HH} of China and India between 1973 *y* 2010, as constructed from data provided in Table A3 and A4.

whereas India has been growing at an annual growth rate of 3.9%. As a result, China managed to achieve a higher level of technical capitalization of its Paid Work sector throughout the period and the gap between the two countries increased abruptly after China's conversion into the world's factory.

We can now study changes on the consumption side of the metabolic pattern, by focusing on the value of EMR_{HH} (Fig. 5). When doing this comparison it can be clearly seen that India has been stagnating around 0.8 MJ/h from the beginning of the study period. This means that the duplication of energy consumption in the household sector – measured when using the extensive variable ET_{HH} – was due exclusively to the increase in population, and not to an increase in the material standard of living of the population. Considering the critical importance of energy consumption to cover basic needs [54] and the several dramatic impacts of that – specially on women and children – pointed by Reddy and Nathan [55], the stagnation on low values of EMR_{HH} during the last 40 years should be considered as a serious problem in India. This fact flags the urgency of exploring alternative renewable energies capable of providing basic services, putting as a priority the poorest households with an empowerment approach, as suggested by Reddy and Nathan [55]. When coming to the characteristics of metabolic pattern of the household sector, China shows an upward progression in the values of EMR_{HH} that are higher than those for India. They started around 1.4 MJ/h between 1978 and 2003, and soared to 1.8 MJ/h in 2010. The different CAGR of EMR_{HH} values are quite different: (i) between 1980 and 1990 it grew at 0.82% per year for China and 0.07% for India; (ii) between 2001 and 2009 the rate was 2.9% for China and 0.8% for India. It should be stressed that between 1998 and 2001 the EMR_{HH} of China was stagnant (Fig. 5) in spite of the robust increase in the values of EMR_{PW} (Fig. 4). The difference in the pace

of growth of the two EMR shows clearly how China sacrificed household consumption to achieve a greater capitalization of Paid Work sector (EMR_{PW}) designed to enhance their international competitiveness in the light of its entry into the WTO in 2001.

The combination of two intensive variables for both countries is shown in Fig. 6. This graph clearly shows progression and scale differences between China and India. Specifically, the EMR_{HH} for India remained stagnant whereas in the case of China the EMR_{HH} as well as the EMR_{PW} soared in the last decade. An assessment of the material standard of living based on the proxy variable EMR_{HH} – the value of India is 0.8 MJ/h and the value of China is between 1.3 and 1.8 MJ/h in the period 1980–2009 – can be compared with the corresponding value of other countries: Brazil 1.46–1.41 MJ/h; Chile 1.54–2.64 MJ/h; Venezuela 2.36–2.07 MJ/h in 1980 and 2000 [49]; Spain 1.67–3.27 MJ/h in 1976 and 1996 [47]; Australia 5.56–6.77 MJ/h, Canada 9.00–8.84 MJ/h and USA 9.47–10.2 MJ/h in 1990 and 2008 [50]. From this comparison, we can see that the value of EMR_{HH} is particularly low for India, but also for China: these values are low also for the standards of developing countries. This suggests that if in China and India industrialization levels will continue to rise with further economic growth (EMR_{PW}), the material living standards will have to rise as well (increasing the value of EMR_{HH}) toward the benchmarks typical of the so-called developed countries, a combination of change that will further increase the total energy consumption (TET).

The relationship between the energy consumption per hour of work (EMR_{PW}) and the economic labor productivity (ELP_{PW}) has been found in several studies of biophysical economics for countries like Spain [47], Ecuador [56] and Australia [50]. This correlation is also given in the case of China and India as seen in Figs. 7 and 8. This relationship is logical if it is assumed that higher energy consumption per hour of work indicates greater capitalization of production, implying larger costs that will not be covered unless this change allows for greater economic labor productivity (ELP_{PW}). However, at level $n-2$ it will be seen that there are certain productive sectors more sensitive to this relationship than others.

Figs. 7a and 8a show the evolution of EMR_{PW} and ELP_{PW} between 1973 and 2009 for both countries. It can be seen that China has higher labor productivity (ELP_{PW}) and has grown significantly since 1990, but especially after 2003 (after settling into the WTO) this value has skyrocketed. For India the growth is lower, but still at a decent rhythm.

3.3. *At the sector level (level $n-2$)*

Once having seen that energy consumption and economic growth of a country do not necessarily lead to improvements in material standards of living for the population (it depends on where the surplus generated in this way is invested: either in more capitalization or in more final consumption), it is necessary to understand what happens within the productive sector (PW sector). In fact, macro-level changes (at the level n) are generated

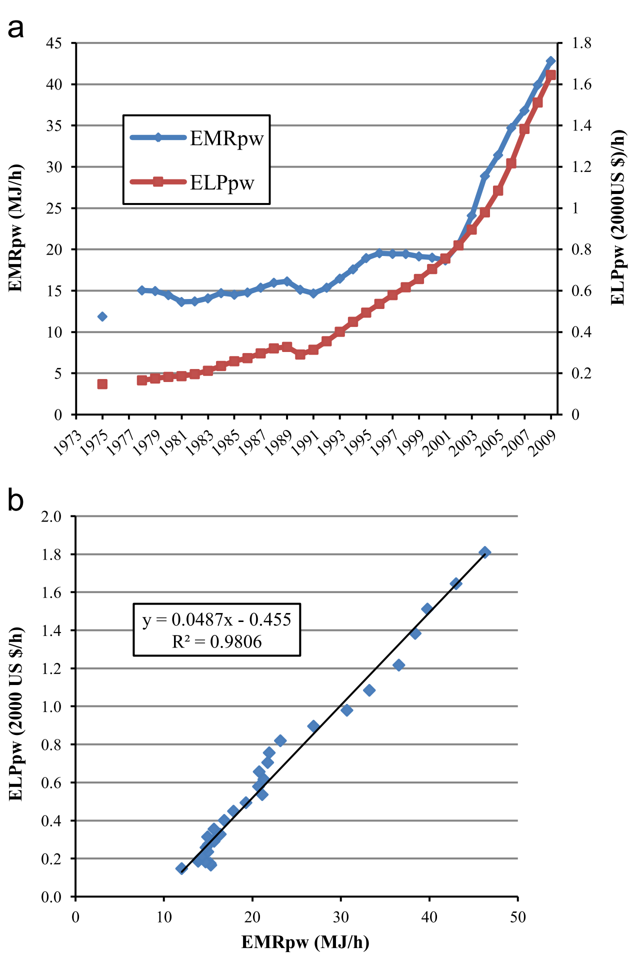

Fig. 7. (a) Evolution of EMR_{PW} and ELP_{PW} of China between 1975 and 2009, as constructed from data provided in Table A3. (b) EMR_{PW} versus ELP_{PW} of China between 1975 and 2009, as constructed from data provided in Table A3.

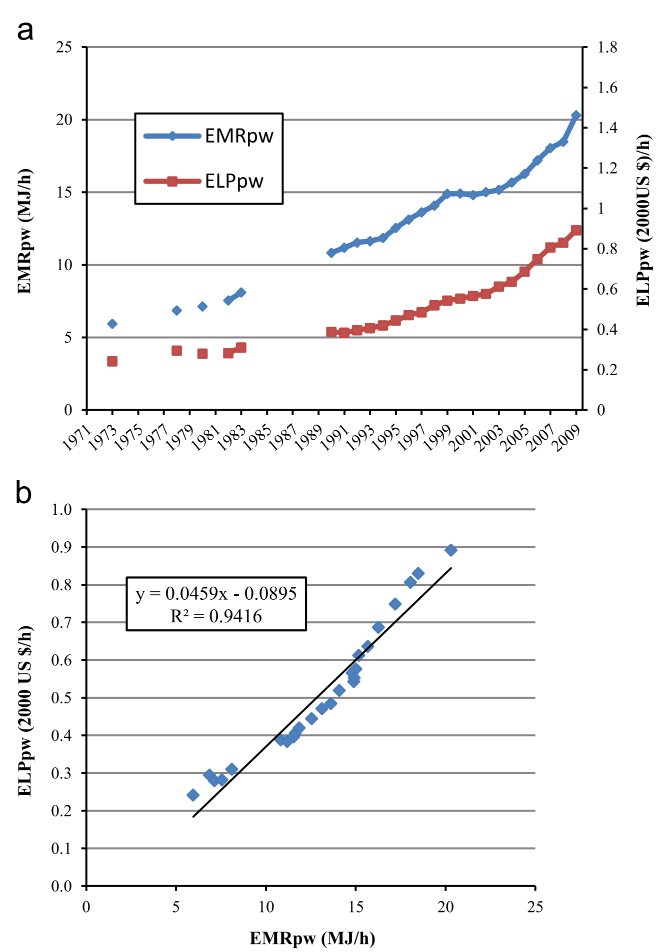

Fig. 8. (a) Evolution of EMR_{PW} and ELP_{PW} of India between 1973 and 2009, as constructed from data provided in Table A4. (b) Evolution of EMR_{PW} and ELP_{PW} of India between 1973 and 2009, as constructed from data provided in Table A4.

by changes in the internal components of the economy [10]: (i) qualitative changes in the relevant characteristics of the various sectors (ELP_i and EMR_i); and (ii) quantitative changes in the size of the various sectors (the profile of distribution of HA_i). This is done by analyzing changes in the metabolic pattern at the level $n-2$ which characterizes the productive sectors of the economy.

Tables A5 and A6 (see Appendix A) list the most relevant data – referring to the level $n-2$ – for the economic sectors of China and India, between 1971 and 2010. In the case of India, only employment data by sector for the years 1994, 2000 and 2005 could be obtained. Therefore, it was not possible to build a full representation based on all the extensive variables such as HA_{AG}, HA_{PS} and HA_{SG}; nor intensive ones arising from these: EMR_{AG}, EMR_{PS}, EMR_{SG}, ELP_{AG}, ELP_{PS} and ELP_{SG}.

Fig. 9a shows the evolution of the energy metabolism rate of productive sectors of China between 1975 and 2009. The industrial sector is undoubtedly the sector with the large rate of energy consumption per hour of labor (EMR_{PS}). This is due to the increasing use of machinery and the growth of infrastructures. The EMR_{PS} of China shows more or less stable behavior between 60 and 80 MJ/h between 1975 and 1999. Nevertheless, from 2000 the EMR_{PS} shoots up at a high rate and leads this indicator up to 147.7 MJ/h in 2010. Once again, it is China's entry into the WTO in 2001 which explains this sudden change. This moment of change also coincided with a growth of EMR_{AG}, which goes from 0.9 MJ/h in 2000 to 2.04 MJ/h in 2010 reflecting an increase in the use of inputs in the agriculture during this period (see Table A5). This increase in the capitalization of agriculture can be explained by the move of huge amounts of workers from farming to go to the cities to work in industry [12]. Furthermore, the service sector shows a similar trend: rising from an EMR_{SG} of 7 MJ/h in 2000 to 9.42 MJ/h in 2010 (see Table A5), indicating an increased use of motorized vehicles in transport and more computerization of administrative tasks.

In the case of India very little EMR_i data is available due to the lack of information on the number of workers employed in each sector of the economy and their work-load per year. However, energy consumption per hour follows the same hierarchy than in China: $EMR_{PS} > EMR_{SG} > EMR_{AG}$ (Fig. 9b). Moreover, India's industrial sector shows a rise in the EMR_{PS} since 1994 that seems stuck around 80 MJ/h between 2000 and 2005. These values are similar to those of China before the year 2000 – the EMR_{PS} of India is 82.66 MJ/h while it is 86.28 for China. Nonetheless, the decline of

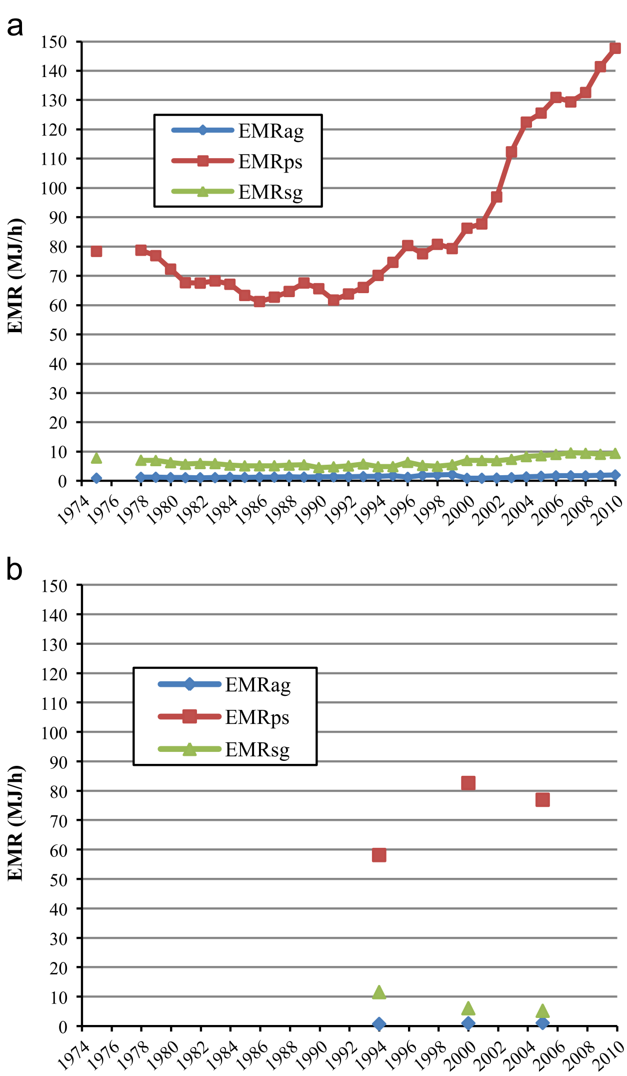

Fig. 9. (a) Evolution of EMR_{AG}, EMR_{PS} and EMR_{SG} of China between 1975 and 2010, as constructed from data provided in Table A5. (b) Evolution of EMR_{AG}, EMR_{PS} and EMR_{SG} of India for years 1994, 2000 and 2005, as constructed from data provided in Table A6.

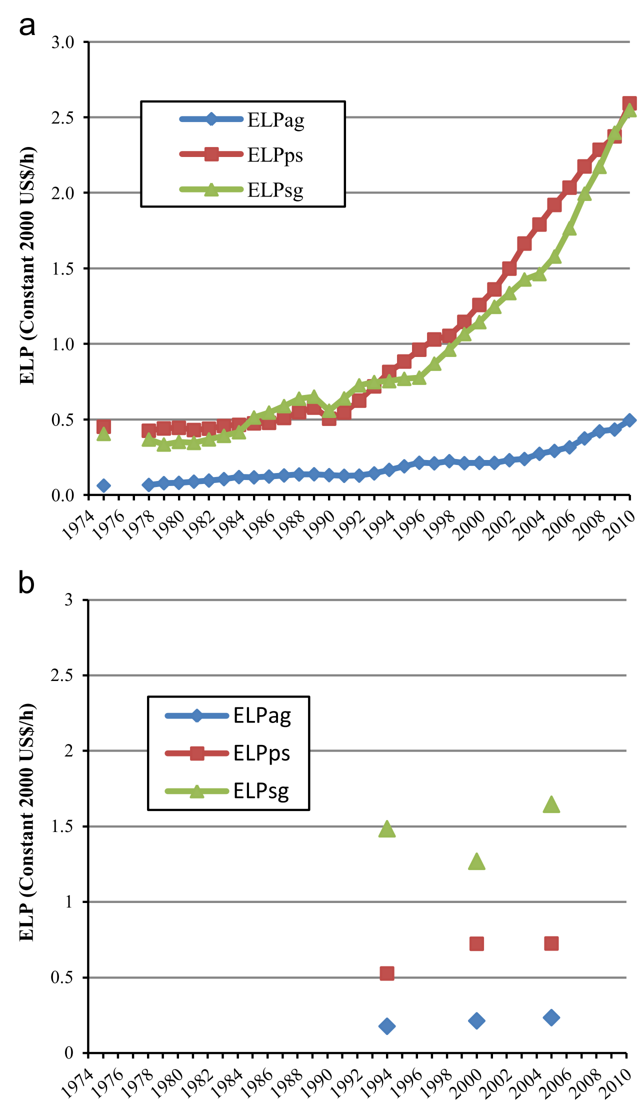

Fig. 10. (a) Evolution of ELP_{AG}, ELP_{PS} and ELP_{SG} of China between 1975 and 2010, as constructed from data provided in Table A5. (b) Evolution of ELP_{AG}, ELP_{PS} and ELP_{SG} of India for years 1994, 2000 and 2005, as constructed from data provided in Table A6.

Indian EMR_{PS} to 76.95 MJ/h in 2005 and the evolution of its GDP and other indicators suggest that since then India's industrial sector has not had the same pattern of strong capitalization of China. As seen in the level $n-1$, the increase in energy consumption in India has not been enough to increase levels of technical capitalization (technical capital per worker indicated by the proxy EMR_i) in industry or in households. It has only been able to offset the increase in population.

Figs. 10a and 10b show how the economic labor productivity of the agricultural sector (ELP_{AG}) was more or less the same in China than in India in 1994 – 0.18 $/h – , but in 2005 China's value was 26% higher – 0.29 $/h versus 0.23 $/h. Likewise, economic labor productivity of the industrial sector (ELP_{PS}) is much higher in China than in India: in 1994 it was 55% higher: 0.81 $/h versus 0.53 $/h; whereas it was 74% higher in 2000: 1.26 $/h compared to 0.72 $/h; and finally it was 165% higher in 2005: 1.92 $/h versus 0.73 $/h. This growing differential largely explains why China's GDP is greater than the Indian one. Finally, the economic labor productivity of the service sector was higher in India than in China – up 49% in 1994: 1.49 $/h versus 0.75 $/h – , a fact that can be explained by the increase in service outsourcing, software companies and R&D in India (taking advantage of the more diffuse use of the English language). However, in recent years China has invested significantly in these areas and is reducing this difference: in 2005 Indian ELP_{SG} was only 4% above that of China: 1.65 $/h compared to 1.58 $/h. In 2010 the ELP_{SG} of China increased to 2.55 $/h which is likely to be greater than in India.

As illustrated in Fig. 10a when considering China the values of ELP_{SG} and the ELP_{PS} are almost similar and following the same trend. This, fact shows clearly the labor intensive nature of the industrial sector of the Chinese economy that get a comparative advantage on the international market, thanks to the possibility of using cheap labor. The situation is even worse for the PS sector in India where, as explained before, the SG sector does better than the PS sector in terms of added value generated per hours of labor. Having seen this last level of analysis, one can say that the fact the ET_{PW} has grown much more in China than in India stems from both the larger weight of GDP_{PS} in the Chinese economy (where $EMR_{PS} > EMR_{SG} > EMR_{AG}$) with a EMR_{PS} continuously increasing, meaning that the difference between Chinese and Indian EMR_{PS} is still rising.

4. Conclusions

This article shows the diverging paths of economic development of China and India in relation to their energy consumption in different

Table A1
Main indicators of China at level *n* from 1971 to 2010.
Sources: IEA (2010) [34], NBSC (2011) [35] & World Bank (2012) [43].

China level *n*							
Year	**TET (PJ)**	**THA (h)**	**GDP (Billions of constant 2000 US$)**	**EMR_{SA} (MJ/h)**	**EEI (MJ/constant 2000US $)**	**MJ per capita**	**GDP per capita (constant 2000 US$)**
1971	16,348	7.47E+12	107	2.19	152.7	19,181	126
1972	17,184	7.64E+12	111	2.25	154.6	19,711	127
1973	17,817	7.81E+12	120	2.28	148.6	19,972	134
1974	18,276	7.96E+12	123	2.30	149.0	20,114	135
1975	20,168	8.10E+12	133	2.49	151.2	21,822	144
1976	20,845	8.21E+12	131	2.54	158.9	22,243	140
1977	22,692	8.32E+12	141	2.73	160.7	23,893	149
1978	24,721	8.43E+12	158	2.93	156.7	25,682	164
1979	25,131	8.54E+12	170	2.94	148.1	25,765	174
1980	25,051	8.65E+12	183	2.90	136.9	25,380	185
1981	24,864	8.77E+12	192	2.84	129.2	24,846	192
1982	25,639	8.90E+12	210	2.88	122.1	25,222	207
1983	26,660	9.02E+12	233	2.95	114.5	25,881	226
1984	28,275	9.14E+12	268	3.09	105.4	27,095	257
1985	28,990	9.27E+12	304	3.13	95.2	27,387	288
1986	29,998	9.42E+12	331	3.19	90.6	27,903	308
1987	31,533	9.57E+12	370	3.29	85.3	28,850	338
1988	33,260	9.73E+12	411	3.42	80.8	29,957	371
1989	33,947	9.87E+12	428	3.44	79.3	30,120	380
1990	36,514	1.00E+13	445	3.65	82.1	31,936	389
1991	35,850	1.01E+13	486	3.53	73.8	30,952	419
1992	37,054	1.03E+13	554	3.61	66.8	31,624	473
1993	39,201	1.04E+13	632	3.78	62.0	33,076	533
1994	40,988	1.05E+13	715	3.90	57.3	34,200	596
1995	43,802	1.06E+13	793	4.13	55.3	36,164	655
1996	45,368	1.07E+13	872	4.23	52.0	37,069	713
1997	46,911	1.08E+13	953	4.33	49.2	37,946	771
1998	47,803	1.09E+13	1028	4.37	46.5	38,315	824
1999	47,414	1.10E+13	1106	4.30	42.9	37,694	879
2000	49,517	1.11E+13	1198	4.46	41.3	39,069	946
2001	50,330	1.12E+13	1298	4.50	38.8	39,435	1017
2002	53,008	1.13E+13	1416	4.71	37.4	41,267	1102
2003	60,303	1.13E+13	1558	5.33	38.7	46,664	1205
2004	67,956	1.14E+13	1715	5.97	39.6	52,279	1319
2005	73,276	1.15E+13	1909	6.40	38.4	56,041	1460
2006	80,053	1.15E+13	2151	6.95	37.2	60,901	1637
2007	84,357	1.16E+13	2457	7.29	34.3	63,844	1859
2008	87,341	1.16E+13	2693	7.51	32.4	65,768	2027
2009	94,175	1.17E+13	2940	8.06	32.0	70,569	2203
2010	101,200	1.17E+13	3246	8.62	31.2	75,471	2421

Table A2
Main indicators of India at level n from 1971 to 2010.
Sources: IEA [34], OECD [41] and World Bank [43].

India level *n*

Year	TET (PJ)	THA (h)	GDP (Billions of constant 2000 US$)	EMR_{SA} (MJ/h)	EEI (MJ/ constant 2000US $)	MJ per capita	GDP per capita (constant 2000 US$)
1971	6551	4.96E+12	119		55.0	11,561	210
1972	6704	5.08E+12	118		56.6	11,562	204
1973	6886	5.20E+12	122	1.32	56.3	11,602	206
1974	7175	5.32E+12	124		57.9	11,809	204
1975	7441	5.45E+12	135		55.1	11,962	217
1976	7748	5.58E+12	137		56.4	12,164	216
1977	7964	5.71E+12	147		54.0	12,209	226
1978	7995	5.85E+12	156	1.37	51.3	11,970	233
1979	8370	5.99E+12	148		56.7	12,240	216
1980	8589	6.13E+12	158	1.40	54.5	12,270	225
1981	9044	6.28E+12	167		54.1	12,623	233
1982	9405	6.42E+12	173	1.46	54.4	12,829	236
1983	9718	6.57E+12	185	1.48	52.4	12,956	247
1984	10,141	6.72E+12	193	1.51	52.7	13,219	251
1985	10,668	6.87E+12	203	1.55	52.7	13,598	258
1986	11,066	7.03E+12	212	1.58	52.1	13,797	265
1987	11,497	7.18E+12	221	1.60	52.1	14,025	269
1988	12,117	7.34E+12	242	1.65	50.1	14,465	289
1989	12,708	7.50E+12	256	1.70	49.6	14,851	300
1990	13,261	7.65E+12	270	1.73	49.0	15,177	310
1991	13,795	7.81E+12	273	1.77	50.5	15,467	307
1992	14,345	7.97E+12	288	1.80	49.7	15,763	317
1993	14,673	8.13E+12	302	1.80	48.6	15,808	325
1994	15,242	8.29E+12	322	1.84	47.3	16,106	340
1995	16,089	8.45E+12	347	1.90	46.4	16,682	359
1996	16,608	8.61E+12	373	1.93	44.6	16,903	379
1997	17,258	8.76E+12	388	1.97	44.5	17,249	388
1998	17,679	8.92E+12	412	1.98	42.9	17,358	404
1999	18,771	9.08E+12	442	2.07	42.4	18,114	427
2000	19,143	9.23E+12	460	2.07	41.6	18,164	437
2001	19,448	9.39E+12	484	2.07	40.2	18,152	452
2002	19,992	9.54E+12	502	2.10	39.8	18,363	462
2003	20,494	9.69E+12	544	2.12	37.6	18,532	492
2004	21,733	9.84E+12	590	2.21	36.9	19,353	525
2005	22,578	9.99E+12	644	2.26	35.0	19,805	565
2006	23,729	1.01E+13	704	2.34	33.7	20,508	609
2007	25,071	1.03E+13	773	2.44	32.4	21,355	659
2008	26,213	1.04E+13	812	2.51	32.3	22,012	681
2009	28,269	1.06E+13	885	2.67	31.9	23,407	733
2010	29,002	1.07E+13	963	2.70	30.1	23,682	787

sectors. The MuSIASEM approach makes it possible to individuate a fragility in China's models and a systemic weakness in the Indian's model. In relation to China, the fast economic development depends on three specific factors: (i) the effects of the one child policy that gave to China the largest work force (both in number and in percentage over the population) in the world. However, this effect will vanish in a decade or two and will backfire (sudden aging of population); (ii) the relative supply of cheap oil. This factor will vanish too, because of the increasing demand worldwide coupled to an increasing cost of extraction of fossil energy; (iii) the possibility to re-invest the majority of the economic revenues in the capitalization of the economy, slowing down in the first period of economic growth the increase in the consumption of the households. Also in this case, the compression of final consumption cannot be kept for a long period of time, since this policy tends to generate growing inequalities and socio-environmental injustices[1] leading to social unrests[2]. In relation to India, the comparison shows a different story, the demographic momentum and a more relaxed control on the flows of investments in the economy did not result in a quick accumulation of capital per capita in the economy (a structural economic growth of the industrial sector). This leaves the economy of India with both a weak internal demand and a low competitiveness – in terms of industrial infrastructures – in relation to China on the international market.

The MuSIASEM approach makes it possible to quantify the factors determining these differences. The large differences in the levels of development between China and India are due to the greater size, capitalization level and pace of growth of China's industrial sector, especially since its entry into the WTO in 2001. In this regard, China has capitalized all sectors to a greater extent (EMR*i*) a fact that translates into a boosting of economic labor productivity (ELP*i*) and GDP, but also its total energy consumption (TET). Therefore, in this phase of industrialization China has at the moment an advantaged position over India, with a more developed infrastructure and a larger level of technical capitalization of economic sectors determining a higher economic labor productivity. However, when comparing China and India energy metabolic rates with the metabolic rates of other countries available from previous studies (Brazil, Chile, Venezuela [49]; Spain [47], Australia, Canada, USA [50]) we can see that their EMR_{HH} and EMR_{PW} are still low. This fact reinforces the conclusion that the

[1] http://www.utne.com/environment/environmental-activists-zm0z13jfzwil.aspx#axzz2WCmuAkrk, http://www.guardian.co.uk/environment/2012/jun/19/environment-activist-deaths [accessed 17.07.13].
[2] https://chinastrikes.crowdmap.com/ [accessed 17.07.13].

value of TET will further increase in the future in both countries. When looking at the Indian and Chinese energy mix, one can conclude that these achievements have been based on an increased dependency on fossil energy. This increased dependency has taken place at the very same moment in which it is becoming clear that a cheap supply of imported energy is no longer an option. In this sense, the strong correlation between GDP and TET (for an overview see Table 1 of Coers and Sanders [57]) suggests that the social and environmental impact will continue to increase in the coming years.

All these questions introduce uncertainty about the future metabolic pattern of China and India, but also about the stability of the future metabolic pattern of the rest of the world, due to the huge weight in the world economy of these two economies. The end of the era of cheap-oil (determined by the peak of conventional oil) and the threat of climate change will shape future energy policies. In fact, environmental degradation implied by the extraction of non-conventional fossil energy reserves and the combustion of fossil fuels of lower quality will become more and more relevant at the moment of developing new energy policies. The development of renewable energy sources will be a must in order to cope with the increases in future energy demand. However, according to the characterization given by MuSIASEM, alternative energy systems will have to be: (i) feasible (compatible with external constraints); (ii) viable (compatibility with internal constraints – i.e. requiring a limited amount of production factors and economic investments) and (iii) desirable (compatibility with human expectations). In relation to desirability a 100% alternative energy scenario will probably not deliver the same amount of (energy) services to which society is used to nowadays… [33]. The Economic Energy Intensity of a country can be reduced by structural changes: moving from industrial production to a service economy – as done by Europe [10] and USA [50] – however this does not imply dematerialization of the world's economy. The economies of EU and USA continue to consume industrial products produced elsewhere (China and India in this case). Therefore, these structural changes in developed economies imply just a cost shifting of social and environmental degradation to other countries. In a global economy the effect of changes have to be analyzed at the global scale!

Finally, both China and India have still low levels of household energy consumption and a size of the agricultural sector – both in terms of workers and the relative sectorial share of GDP – much larger than other developed countries. This situation suggests that

Table A3
Main indicators of China at level $n-1$ from 1971 to 2010.
Sources: IEA [34], NBSC [35], ILO [42] and World Bank [43].

China level $n-1$

Year	ET_{PW} (PJ)	ET_{HH} (PJ)	HA_{PW} (h)	HA_{HH} (h)	EMR_{PW} (MJ/h)	EMR_{HH} (MJ/h)	ELP_{PW} (Thousands of constant 2000 US S/h)	ELP_{PW}/EMR_{PW} (Thousands of constant 2000 US S/MJ)
1971	8098	8250						
1972	8670	8514						
1973	9110	8707						
1974	9418	8857						
1975	10,847	9321	9.02E+11	7.19E+12	12.02	1.30	0.15	12.3
1976	11,383	9462						
1977	12,821	9871						
1978	14,530	10,191	9.49E+11	7.48E+12	15.31	1.36	0.17	10.9
1979	14,772	10,359	9.69E+11	7.58E+12	15.24	1.37	0.18	11.5
1980	14,733	10,318	1.00E+12	7.65E+12	14.72	1.35	0.18	12.4
1981	14,336	10,527	1.03E+12	7.73E+12	13.88	1.36	0.19	13.4
1982	14,932	10,707	1.07E+12	7.84E+12	13.96	1.37	0.20	14.1
1983	15,713	10,947	1.10E+12	7.93E+12	14.33	1.38	0.21	14.8
1984	17,037	11,238	1.14E+12	8.00E+12	14.97	1.40	0.24	15.7
1985	17,391	11,599	1.18E+12	8.10E+12	14.77	1.43	0.26	17.5
1986	18,190	11,808	1.21E+12	8.21E+12	15.03	1.44	0.27	18.2
1987	19,446	12,087	1.25E+12	8.33E+12	15.61	1.45	0.30	19.0
1988	20,792	12,467	1.28E+12	8.44E+12	16.22	1.48	0.32	19.8
1989	21,386	12,560	1.31E+12	8.57E+12	16.38	1.47	0.33	20.0
1990	23,945	12,568	1.53E+12	8.49E+12	15.68	1.48	0.29	18.6
1991	23,084	12,766	1.54E+12	8.60E+12	14.95	1.48	0.31	21.0
1992	24,438	12,615	1.56E+12	8.70E+12	15.67	1.45	0.36	22.7
1993	26,513	12,688	1.58E+12	8.81E+12	16.83	1.44	0.40	23.8
1994	28,435	12,553	1.59E+12	8.91E+12	17.88	1.41	0.45	25.1
1995	30,946	12,855	1.60E+12	9.01E+12	19.28	1.43	0.49	25.6
1996	34,333	11,035	1.63E+12	9.10E+12	21.12	1.21	0.54	25.4
1997	34,076	12,835	1.65E+12	9.18E+12	20.70	1.40	0.58	28.0
1998	35,481	12,321	1.67E+12	9.26E+12	21.31	1.33	0.62	29.0
1999	34,971	12,443	1.68E+12	9.34E+12	20.78	1.33	0.66	31.6
2000	36,942	12,574	1.70E+12	9.40E+12	21.74	1.34	0.71	32.4
2001	37,607	12,723	1.72E+12	9.46E+12	21.91	1.34	0.76	34.5
2002	40,036	12,972	1.73E+12	9.53E+12	23.18	1.36	0.82	35.4
2003	46,799	13,503	1.74E+12	9.58E+12	26.92	1.41	0.90	33.3
2004	53,728	14,228	1.75E+12	9.64E+12	30.69	1.48	0.98	31.9
2005	58,470	14,806	1.76E+12	9.69E+12	33.23	1.53	1.08	32.6
2006	64,619	15,434	1.77E+12	9.75E+12	36.56	1.58	1.22	33.3
2007	68,184	16,173	1.78E+12	9.80E+12	38.40	1.65	1.38	36.0
2008	70,877	16,464	1.78E+12	9.85E+12	39.79	1.67	1.51	38.0
2009	76,910	17,265	1.79E+12	9.90E+12	43.03	1.74	1.65	38.2
2010	83,037	18,163	1.79E+12	9.95E+12	46.29	1.82	1.81	39.1

both India and China will continue to require strong injections of technical capitalization and will have to increase their total energy consumption in order to absorb labor from rural areas into the growing urban economy, to remain competitive internationally with their economies, increase domestic consumption, and boost their internal production of food for their food security. Failure to meet any of these points, especially the last two: a quick increase in household energy consumption – providing a badly needed increase in the energy services of the poorest fraction of the population – and the possibility of guarantee cheap food to the poor may trigger social unrest, given that inequalities and socio-economic injustices are already serious in these countries.

From this analysis some peculiarities of these countries can also be noted. For example, China shows a very high fraction of human activity allocated to Paid Work which makes its economy very competitive at the moment. This positive peculiarity is largely due to its demographic structure: a low dependency ratio because of the past one-child policy. However, this plus of the Chinese economy can become a major liability in the future with a sudden aging of the population, that is composed now of a vast majority of adults. A second peculiarity is represented by the fact that even though the economic energy intensity is decreasing significantly for both countries, the effect the strong pace of growth moving-up the value of the metabolic characteristics of their various sectors toward the benchmarks typical of developed countries (EMR_{PW} and EMR_{HH}) implies that such a decrease has no appreciable effect on the total energy consumption (TET) of the economy of both countries.

Considering the size of these two giants-countries and when considering the trends of change in the energetic metabolic pattern of China and India we can only conclude that it is extremely important to pay more attention to the biophysical roots of the economic process and to the existing link between the availability of resources and the ability of the economic process to guarantee an adequate production and consumption of goods and services for a changing population.

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Table A4
Main indicators of India at level $n-1$ from 1971 to 2010.
Sources: IEA [34], OECD [41], ILO [42] and World Bank [43].

India level $n-1$								
Year	**ET_{PW} (PJ)**	**ET_{HH} (PJ)**	**HA_{PW} (h)**	**HA_{HH} (h)**	**EMR_{PW} (MJ/h)**	**EMR_{HH} (MJ/h)**	**ELP_{PW} (constant 2000 US $/h)**	**ELP_{PW}/EMR_{PW} (thousands of constant 2000 US $/MJ)**
1971	2963	3588						
1972	3041	3664						
1973	3154	3732	5.06E+11	4.69E+12	6.23	0.80	0.24	38.8
1974	3373	3802						
1975	3538	3903						
1976	3741	4007						
1977	3853	4111						
1978	3789	4206	5.29E+11	5.32E+12	7.17	0.79	0.29	41.1
1979	4067	4304						
1980	4199	4390	5.63E+11	5.57E+12	7.46	0.79	0.28	37.5
1981	4563	4481						
1982	4822	4584	6.13E+11	5.81E+12	7.87	0.79	0.28	35.8
1983	5046	4672	5.98E+11	5.97E+12	8.44	0.78	0.31	36.7
1984	5371	4769						
1985	5797	4870						
1986	6092	4974						
1987	6392	5105						
1988	6898	5219						
1989	7362	5346						
1990	7828	5433	6.97E+11	6.96E+12	11.24	0.78	0.39	34.6
1991	8262	5533	7.12E+11	7.10E+12	11.60	0.78	0.38	33.1
1992	8715	5630	7.28E+11	7.24E+12	11.96	0.78	0.40	33.1
1993	8972	5701	7.44E+11	7.39E+12	12.06	0.77	0.41	33.7
1994	9433	5,809	7.68E+11	7.52E+12	12.29	0.77	0.42	34.2
1995	10,156	5933	7.80E+11	7.67E+12	13.03	0.77	0.44	34.1
1996	10,678	5930	7.91E+11	7.82E+12	13.49	0.76	0.47	34.9
1997	11,198	6060	8.00E+11	7.96E+12	13.99	0.76	0.48	34.6
1998	11,480	6199	7.93E+11	8.13E+12	14.48	0.76	0.52	35.9
1999	12,462	6309	8.15E+11	8.26E+12	15.30	0.76	0.54	35.5
2000	12,752	6390	8.32E+11	8.40E+12	15.32	0.76	0.55	36.1
2001	12,978	6470	8.56E+11	8.53E+12	15.17	0.76	0.57	37.3
2002	13,388	6604	8.72E+11	8.67E+12	15.36	0.76	0.58	37.5
2003	13,752	6742	8.89E+11	8.80E+12	15.47	0.77	0.61	39.6
2004	14,775	6959	9.26E+11	8.91E+12	15.95	0.78	0.64	39.9
2005	15,478	7101	9.38E+11	9.05E+12	16.50	0.78	0.69	41.6
2006	16,416	7312	9.41E+11	9.19E+12	17.45	0.80	0.75	42.9
2007	17,575	7496	9.59E+11	9.32E+12	18.33	0.80	0.81	44.0
2008	18,530	7683	9.78E+11	9.45E+12	18.96	0.81	0.83	43.8
2009	20,395	7874	9.93E+11	9.59E+12	20.54	0.82	0.89	43.4
2010	20,930	8071		1.07E+13				

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Appendix A

See Tables A1–A6.

Table A5
Main indicators of China at level $n-2$ from 1971 to 2010.
Sources: IEA [34], NBSC [35], ILO [42], World Bank [43] and UN [45].

China level $n-2$

Year	ET_{AG} (PJ)	ET_{PS} (PJ)	ET_{SG} (PJ)	HA_{AG} (h)	HA_{PS} (h)	HA_{SG} (h)	GDP_{AG} (billions of constant 2000 US$)	GDP_{PS} (billions of constant 2000 US$)	GDP_{SG} (billions of constant 2000 US$)	EMR_{AG} (MJ/h)	EMR_{PS} (MJ/h)	EMR_{SG} (MJ/h)	ELP_{AG} (constant 2000 US$/h)	ELP_{PS} (constant 2000 US$/h)	ELP_{SG} (constant 2000 US$/h)
1971	480	7109	509				36	41	30						
1972	530	7589	551				37	43	31						
1973	576	7943	591				40	47	34						
1974	602	8181	636				42	48	33						
1975	660	9490	696	6.92E+11	1.21E+11	8.90E+10	43	55	36	0.95	78.39	7.82	0.06	0.45	0.40
1976	679	9998	707				43	54	34						
1977	746	11,296	778				42	61	38						
1978	825	12,855	850	6.65E+11	1.63E+11	1.20E+11	44	69	44	1.24	78.76	7.07	0.07	0.43	0.37
1979	848	13,037	887	6.73E+11	1.70E+11	1.27E+11	53	75	42	1.26	76.90	6.98	0.08	0.44	0.33
1980	789	13,096	847	6.84E+11	1.81E+11	1.35E+11	55	80	48	1.15	72.31	6.26	0.08	0.44	0.35
1981	782	12,727	828	7.00E+11	1.88E+11	1.45E+11	62	81	50	1.12	67.67	5.71	0.09	0.43	0.34
1982	801	13,246	885	7.25E+11	1.96E+11	1.48E+11	69	86	55	1.10	67.54	5.96	0.10	0.44	0.37
1983	832	13,929	953	7.32E+11	2.04E+11	1.61E+11	77	93	63	1.14	68.29	5.93	0.10	0.46	0.39
1984	895	15,133	1010	7.25E+11	2.25E+11	1.87E+11	86	105	78	1.23	67.15	5.39	0.12	0.46	0.42
1985	890	15,459	1041	7.32E+11	2.44E+11	2.02E+11	85	116	104	1.22	63.35	5.16	0.12	0.47	0.51
1986	944	16,144	1103	7.34E+11	2.64E+11	2.12E+11	89	126	116	1.28	61.25	5.19	0.12	0.48	0.55
1987	982	17,291	1173	7.44E+11	2.76E+11	2.26E+11	96	140	133	1.32	62.75	5.19	0.13	0.51	0.59
1988	1029	18,475	1288	7.58E+11	2.86E+11	2.39E+11	103	156	152	1.36	64.70	5.39	0.14	0.55	0.64
1989	1018	19,021	1347	7.81E+11	2.81E+11	2.43E+11	107	163	158	1.30	67.59	5.54	0.14	0.58	0.65
1990	1265	21,369	1311	9.14E+11	3.26E+11	2.87E+11	120	165	160	1.38	65.63	4.57	0.13	0.51	0.56
1991	1314	20,340	1430	9.19E+11	3.29E+11	2.96E+11	117	180	189	1.43	61.76	4.83	0.13	0.55	0.64
1992	1298	21,533	1607	9.09E+11	3.37E+11	3.13E+11	116	211	227	1.43	63.83	5.13	0.13	0.62	0.73
1993	1320	23,231	1962	8.85E+11	3.52E+11	3.38E+11	126	253	253	1.49	66.06	5.80	0.14	0.72	0.75
1994	1379	25,253	1803	8.61E+11	3.60E+11	3.70E+11	143	293	279	1.60	70.18	4.87	0.17	0.81	0.75
1995	1525	27,457	1964	8.35E+11	3.68E+11	4.02E+11	159	325	309	1.83	74.63	4.89	0.19	0.88	0.77
1996	1020	30,601	2712	8.18E+11	3.81E+11	4.27E+11	174	366	331	1.25	80.37	6.36	0.21	0.96	0.78
1997	1594	30,156	2325	8.19E+11	3.89E+11	4.39E+11	172	400	381	1.95	77.55	5.30	0.21	1.03	0.87
1998	1722	31,517	2242	8.27E+11	3.90E+11	4.49E+11	185	411	432	2.08	80.79	5.00	0.22	1.05	0.96
1999	1824	30,610	2538	8.41E+11	3.86E+11	4.57E+11	177	442	486	2.17	79.32	5.56	0.21	1.15	1.07
2000	761	32,884	3297	8.47E+11	3.81E+11	4.71E+11	180	479	539	0.90	86.28	7.00	0.21	1.26	1.14
2001	792	33,471	3344	8.55E+11	3.81E+11	4.79E+11	182	519	597	0.93	87.74	6.98	0.21	1.36	1.25
2002	847	35,732	3457	8.61E+11	3.69E+11	4.98E+11	198	552	666	0.98	96.96	6.94	0.23	1.50	1.34
2003	965	42,050	3785	8.51E+11	3.74E+11	5.13E+11	202	623	732	1.13	112.35	7.38	0.24	1.66	1.43
2004	1137	48,098	4493	8.19E+11	3.93E+11	5.39E+11	223	703	789	1.39	122.49	8.33	0.27	1.79	1.46
2005	1252	52,427	4791	7.86E+11	4.18E+11	5.56E+11	229	802	878	1.59	125.57	8.61	0.29	1.92	1.58
2006	1305	58,132	5182	7.51E+11	4.44E+11	5.73E+11	237	904	1011	1.74	130.92	9.05	0.32	2.03	1.77
2007	1269	61,374	5540	7.22E+11	4.74E+11	5.79E+11	270	1032	1155	1.76	129.38	9.57	0.37	2.18	1.99
2008	1216	64,047	5614	7.03E+11	4.83E+11	5.95E+11	296	1104	1292	1.73	132.60	9.44	0.42	2.29	2.17
2009	1265	70,061	5584	6.79E+11	4.95E+11	6.13E+11	294	1176	1470	1.86	141.43	9.11	0.43	2.37	2.40
2010	1341	75,816	5880	6.56E+11	5.13E+11	6.24E+11	325	1331	1591	2.04	147.71	9.42	0.49	2.59	2.55

Table A6
Main indicators of India at level $n-2$ from 1971 to 2010.
Sources: IEA [34], OECD [41], ILO [42], World Bank [43], UN [45] and Planning Commission [44].

India level $n-2$

Year	ET_{AG} (PJ)	ET_{PS} (PJ)	ET_{SG} (PJ)	HA_{AG} (h)	HA_{PS} (h)	HA_{SG} (h)	GDP_{AG} (billions of constant 2000 US$)	GDP_{PS} (billions of constant 2000 US$)	GDP_{SG} (billions of constant 2000 US$)	EMR_{AG} (MJ/h)	EMR_{PS}(MJ/h)	EMR_{SG} (MJ/h)	ELP_{AG} (constant 2000 US$/h)	ELP_{PS} (constant 2000 US$/h)	ELP_{SG} (constant 2000 US$/h)
1971	58	2273	632				50	20	49						
1972	65	2351	624				50	20	49						
1973	72	2460	622				55	20	48						
1974	70	2653	650				52	22	50						
1975	65	2801	672				53	24	58						
1976	71	2991	679				51	26	60						
1977	77	3079	697				56	27	65						
1978	90	2994	706				58	31	67						
1979	92	3206	769				52	31	65						
1980	110	3336	754				58	32	68						
1981	123	3649	791				58	35	73						
1982	109	3915	797				59	36	78						
1983	111	4097	838				65	39	82						
1984	123	4348	900				64	40	89						
1985	133	4773	891				65	45	93						
1986	148	5070	875				66	47	100						
1987	173	5310	909				66	46	108						
1988	185	5728	985				75	53	114						
1989	209	6139	1014				77	56	123						
e1990	233	6522	1073				81	60	130						
1991	269	6858	1135				82	57	134						
1992	286	7267	1162				87	61	141						
1993	325	7480	1168				88	63	151						
1994	381	7824	1229	5.27E+11	1.34E+11	1.06E+11	93	71	158	0.72	58.17	11.56	0.18	0.53	1.49
1995	388	8439	1329				94	80	173						
1996	436	9094	1148				104	86	183						
1997	480	9528	1190				101	85	202						
1998	506	9832	1143				107	87	218						
1999	517	10,731	1214				111	88	243						
2000	481	11,039	1232	4.96E+11	1.34E+11	2.03E+11	106	97	258	0.97	82.66	6.07	0.21	0.72	1.27
2001	467	11,290	1222				111	97	276						
2002	486	11,647	1255				106	106	291						
2003	560	11,936	1257				114	109	321						
2004	568	12,944	1263				112	118	360						
2005	561	13,674	1243	5.22E+11	1.78E+11	2.39E+11	122	129	393	1.08	76.95	5.21	0.23	0.73	1.65
2006	613	14,470	1334				127	148	430						
2007	647	15,487	1440				139	162	472						
2008	666	16,294	1571				138	162	511						
2009	564	18,122	1709				159	168	558						
2010	593	18,512	1825				183	173	607						

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